CONJUGACY OF ELF EMISSION SPECTRA AND POWERS

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***Abstract*:** Conjugate observations of ELF emissions were carried out at Syowa Station in Antarctica and Husafell in Iceland from July 29 to September 18, 1977. The conjugacy of ELF emissions depends on the emission types and local time. The intensity of auroral chorus is always much stronger at Husafell than at Syowa. Frequency-time (f-t) spectral patterns of polar chorus emissions depend on local time at conjugate-pair stations. In the morning sector (06–09 MLT) the lower frequency band at Syowa is stronger than that at Husafell. The conjugacy of emission patterns in f-t spectra is more complex in the daytime sector (09–14 MLT), but the following tendencies are found: i) Differences in the center frequency of each event at the conjugate stations are less than 0.2 kHz in the interval of 09–11 MLT, and in the interval of 11–14 MLT these become larger up to 0.5 kHz. ii) The power of emissions in the frequency range higher than 0.8 kHz at Husafell is about 10 dB stronger than that at Syowa. iii) Higher cutoff frequency of polar chorus is about 1 kHz at Syowa, while that at Husafell extends over 1.5 kHz. Statistically, polar chorus emissions are more often observed at Husafell in the whole local time. Furthermore, occurrences of polar chorus at the conjugate stations depend on geomagnetic activity. When geomagnetic activity is quiet ($Kp \leq 1$) emissions are often observed at Syowa, but emissions are more often observed at Husafell in the moderate and disturbed periods ($Kp \geq 2$).

1. Introduction

Conjugate observations of ELF-VLF emissions and magnetic pulsations were carried out at Syowa and Mizuho Stations in Antarctica and Husafell in Iceland during the period of July 29–September 18, 1977. The geographic and geomagnetic coordinates of Syowa, Mizuho and Husafell are listed in Table 1. Husafell is about 50 km north of the geomagnetic conjugate point of Syowa.

The magnetic pulsation data and the ELF-VLF data used in this study were measured by the same instruments at Husafell, Syowa and Mizuho. The H and D components of magnetic pulsations below 3 Hz were measured with an induction magnetometer and were recorded on magnetic tape (speed, 3 mm s^{-1}) and strip chart (speed, 30 cm h^{-1}). ELF-VLF emissions picked up by standard loop antennas were

Table 1. Locations of Husafell, Syowa and Mizuho Stations.

Station name	Geographic		Geomagnetic		L	Conjugate geographic	
	Latitude	Longitude	Latitude	Longitude		Latitude	Longitude
Husafell	64.7°N	20.9°W	70.2°	74.2°	6.14	68.9°S	40.1°E
Syowa	69.0°S	39.6°E	−70.0°	79.4°	6.02	64.3°N	21.2°W
Mizuho	70.7°S	44.3°E	−72.3°	80.6°	7.04	65.9°N	22.7°W

recorded in three different ways at Syowa and Husafell. First, the intensities of emissions at selected frequencies (0.75, 1.0, 2.0, 4.0 and 8.0 kHz) measured using filters with the high Q value of 40 were recorded on strip chart. Second, wide band signals in the frequency range of 0.2–20 kHz were continuously recorded on magnetic tape. Third, wide band ELF-VLF signals, the H and D components of magnetic pulsations and auroral luminosity (4278 Å) were simultaneously recorded on the same magnetic tapes in order to examine correlations between these phenomena.

SATO *et al.* (1980) reported qualitative results for the conjugacy of ELF-VLF emissions observed at Syowa and Husafell. They showed that the conjugacy of ELF-VLF emissions depends on their types, such as polar chorus, quasi-periodic emissions, bursts of discrete emissions, auroral chorus and auroral hiss. Polar chorus and quasi-periodic emissions are commonly observed simultaneously at the conjugate-pair stations. The conjugacy of bursts of discrete emissions, auroral chorus and auroral hiss emissions is generally low. The intensity of auroral hiss is much stronger at Syowa (winter hemisphere) than at Husafell (summer hemisphere), and just the opposite tendency is observed for bursts of discrete emissions and auroral chorus.

However, SATO *et al.* (1980) did not report quantitative characteristics of emission power and frequency at the conjugate-pair stations. In this paper, we calibrated the absolute emission intensity at the conjugate-pair stations, and examined quantitatively local time characteristics of frequency-time (f-t) spectra, emission frequencies and powers. To examine emission power spectra we mostly used the FFT (Fast Fourier Transform) spectrum analyzer (SD-350). Analyzed spectra were calculated by using the M-160 computer system to compare the quantitative differences at the conjugate stations. Statistical analyses for emission frequencies, occurrence local time and Kp dependencies were also done.

2. Local Time Dependence of Emission Frequency

SATO *et al.* (1980) examined the conjugacy of ELF-VLF emission. They analyzed typical emission types by using an expanded f-t spectrum with time. In this study, we made a compressed f-t spectrum with time by using high speed data deduction technique. The compressed f-t spectrum with time affords an easy recognization in the study of diurnal variation of emission frequency and intensity. We carefully analyzed the f-t spectrum at the conjugate station, and found local time dependence of emission type, emission frequency and emission intensity.

2.1. *Early morning sector (00–06 MLT)*

Emission types observed at Syowa and Husafell in the early morning (00–06 MLT)

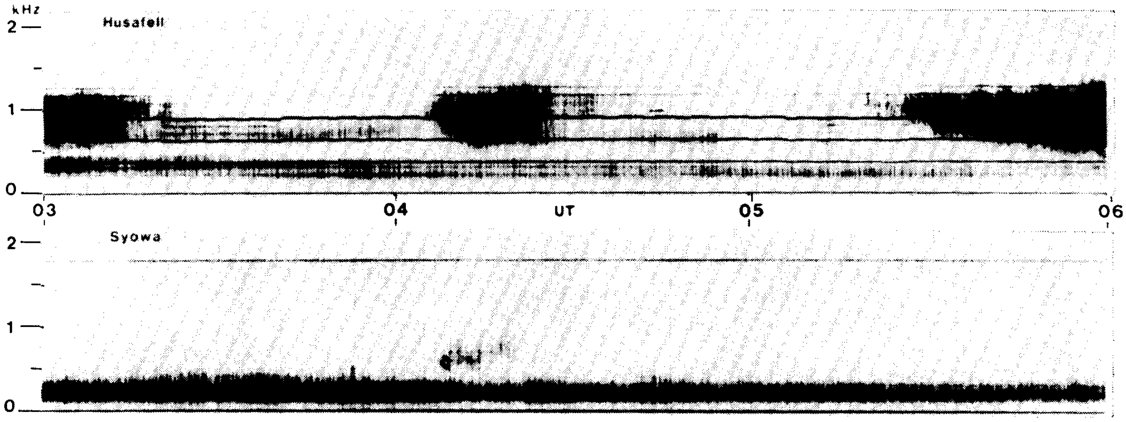

Fig. 1. Frequency-time spectra of ELF emissions observed at the conjugate-pair stations in the time interval of 03–06 UT on August 15, 1977.

are mostly auroral chorus, sometimes auroral hiss and burst of discrete emissions (HAYASHI and KOKUBUN, 1971; SATO *et al.*, 1980). Typical examples of these emissions were shown by HELLIWELL (1965) and HAYASHI and KOKUBUN (1971). Figure 1 shows f-t spectra observed at the conjugate-pair stations in the time interval of 03–06 UT on August 15, 1977. It is clear that emissions are enhanced at Husafell in the time intervals of 0300–0320, 0405–0430 and 0530–0600 UT with the frequency band of 0.6–1.2 kHz. Emission type in these intervals is auroral chorus according to the expanded f-t spectra with time. However, at Syowa Station only weak emissions are enhanced in the interval of 0404–0420 UT. Furthermore, emission frequency at Syowa is lower than that at Husafell in the interval of 0405–0420 UT. From this example we can say that auroral chorus emissions observed at Husafell in the early morning are stronger and have higher frequency bands than at Syowa. The same tendency is observed on July 31, August 8, and August 18, 1977. There is no example to the contrary characteristics during the conjugate campaign period.

2.2. *Morning sector (06–09 MLT)*

A polar chorus band is defined as a continuous quasi-steady noise normally composed of multiple rising tones and having definite upper and lower cutoff frequencies. Polar chorus emissions mostly begin to be observed in the morning from 06 MLT at Syowa (HAYASHI *et al.*, 1968). Emission frequency sometimes increases gradually with time within one hour from a few hundreds heltz to more than one kiloheltz.

Figure 2 shows f-t spectra of emissions observed at Syowa and Husafell in the time interval of 06–08 UT on August 15, 1977. It is clearly found from the f-t spectra at Syowa that emission frequency increases with time from 0.3 kHz to 0.8 kHz during 0600–0700 UT. However, at Husafell such emissions gradually increasing frequency with time are very weak or not observed in this time interval. Emission type at conjugate stations is different. Emission type at Husafell in the time interval of 0600–0640 UT is auroral chorus. Such auroral chorus emissions are very weak at Syowa in this interval. Frequency-time spectral pattern after 07 UT is also different at the conjugate-pair stations. Center frequency of emissions observed at Husafell is nearly 1 kHz, but that at Syowa is less than 0.7 kHz. Furthermore, falling-tone type QP emissions

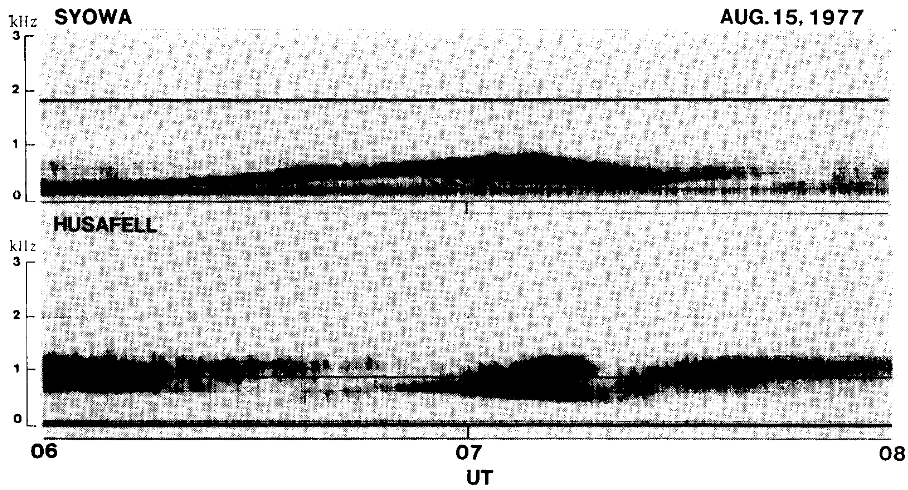

Fig. 2. Same as Fig. 1 for 06–08 UT on August 15, 1977.

modulated by Pc 5 magnetic pulsations (SATO and FUKUNISHI, 1981) are observed only at Syowa Station in the interval of 0640–0710 UT. From these examples, we can say that f-t spectral patterns are different at the conjugate-pair stations in the interval of 06–08 UT. Such examples are observed on August 8, 9 and 19, 1977.

2.3. *Daytime sector (09–14 MLT)*

Conjugacy of emission pattern in the daytime sector (09–14 MLT) is more complex than that in the morning sector. We can distinguish the following four cases by examining the f-t spectra; i) higher frequency band of emissions at Husafell is much stronger than that at Syowa, ii) just opposite characteristics to i), iii) lower frequency band of emissions at Syowa is much stronger than that at Husafell, iv) just opposite chracteristics to iii). Most common cases were i) and iii) during this conjugate campaign period.

Figure 3 shows the f-t spectra of emissions observed at the conjugate-pair stations in the time interval of 09–12 UT on July 31, 1977. It is clearly found from this figure that higher frequency bands of emissions with the center frequency of 1 kHz are much

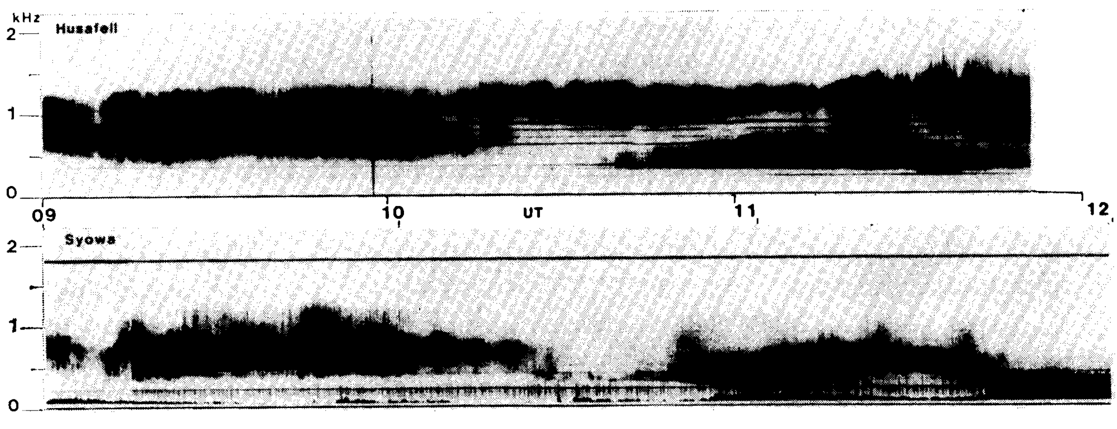

Fig. 3. Same as Fig. 1 for 19–12 UT on July 31, 1977.

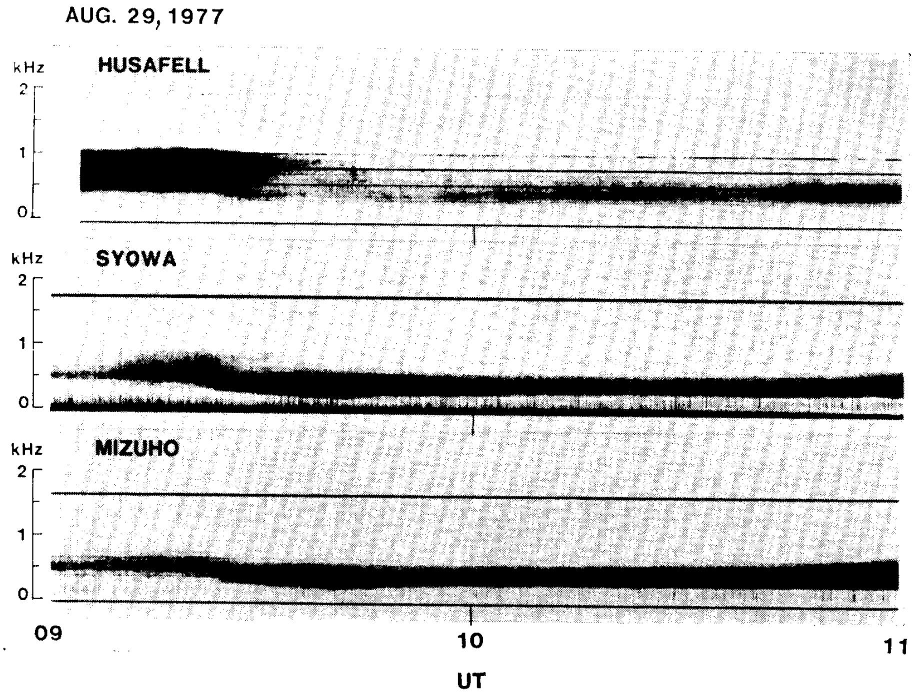

Fig. 4. Frequency-time spectra of polar chorus emissions observed at Husafell, Syowa and Mizuho in the time interval of 09–11 UT on August 29, 1977.

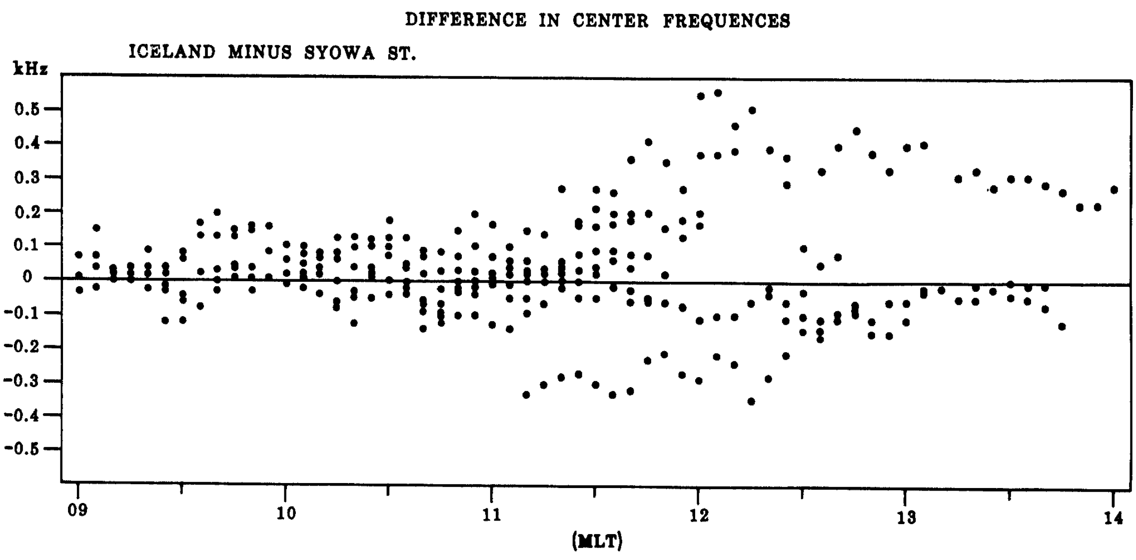

Fig. 5. Difference of center frequency of emissions observed at the conjugate-pair stations in the time interval of 09–14 UT. The ordinate axis shows frequency difference of Δf (fc-(Husafell)−fc(Syowa)), where fc (Husafell) and fc (Syowa) are the center frequency of emissions at Husafell and Syowa, respectively.

stronger at Husafell. Therefore, this example includes case i). Figure 4 shows the f-t spectra of polar chorus emissions observed at three stations, Husafell, Syowa and Mizuho in the interval of 09–11 UT on August 29, 1977. It is interesting that the center of the emission frequency is 0.7 kHz at all stations, but the emission intensity is strongest at Husafell and weakest at Mizuho in the interval of 0900–0930 UT. However, in the interval of 0930–1100 UT the emission frequency becomes low (0.5 kHz) at all stations, but the emission intensity ratio among three stations becomes opposite. The characteristics of the intensity ratio observed at Syowa and Mizuho in this example are the same as those reported by SATO *et al.* (1979). This example includes case i) and iii).

Statistical results of the differences in the center of the emission frequency observed at the conjugate-pair stations in the daytime sector are shown in Fig. 5. Center frequency is defined as the frequency having maximum power density. From this figure it is clear that the differences in the center of the emission frequency in the interval of 09–11 UT are less than 0.2 kHz, and the emission frequency at Husafell is mostly higher than that at Syowa. However, after 1130 UT the differences in the center of the emission frequency become larger (up to 0.5 kHz).

3. Power Spectra at Conjugate-pair Stations

In this section we examine quantitatively the characteristics of emission power observed at the conjugate-pair stations.

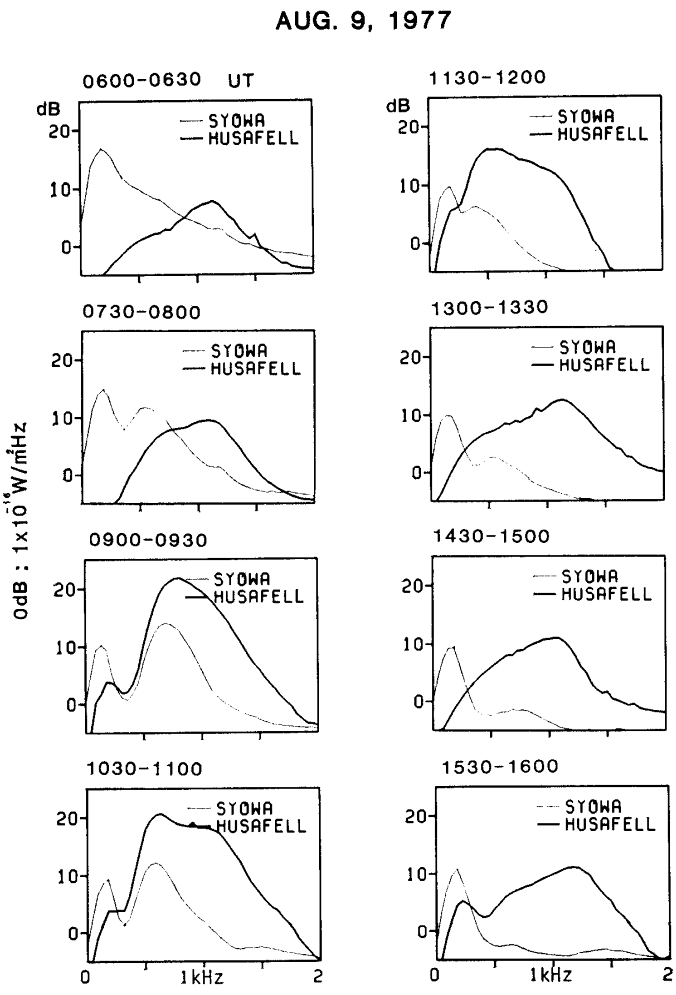

Fig. 6. 30-min averaged power spectra observed at the conjugate-pair stations in the time interval of 06–16 UT on August 9, 1977.

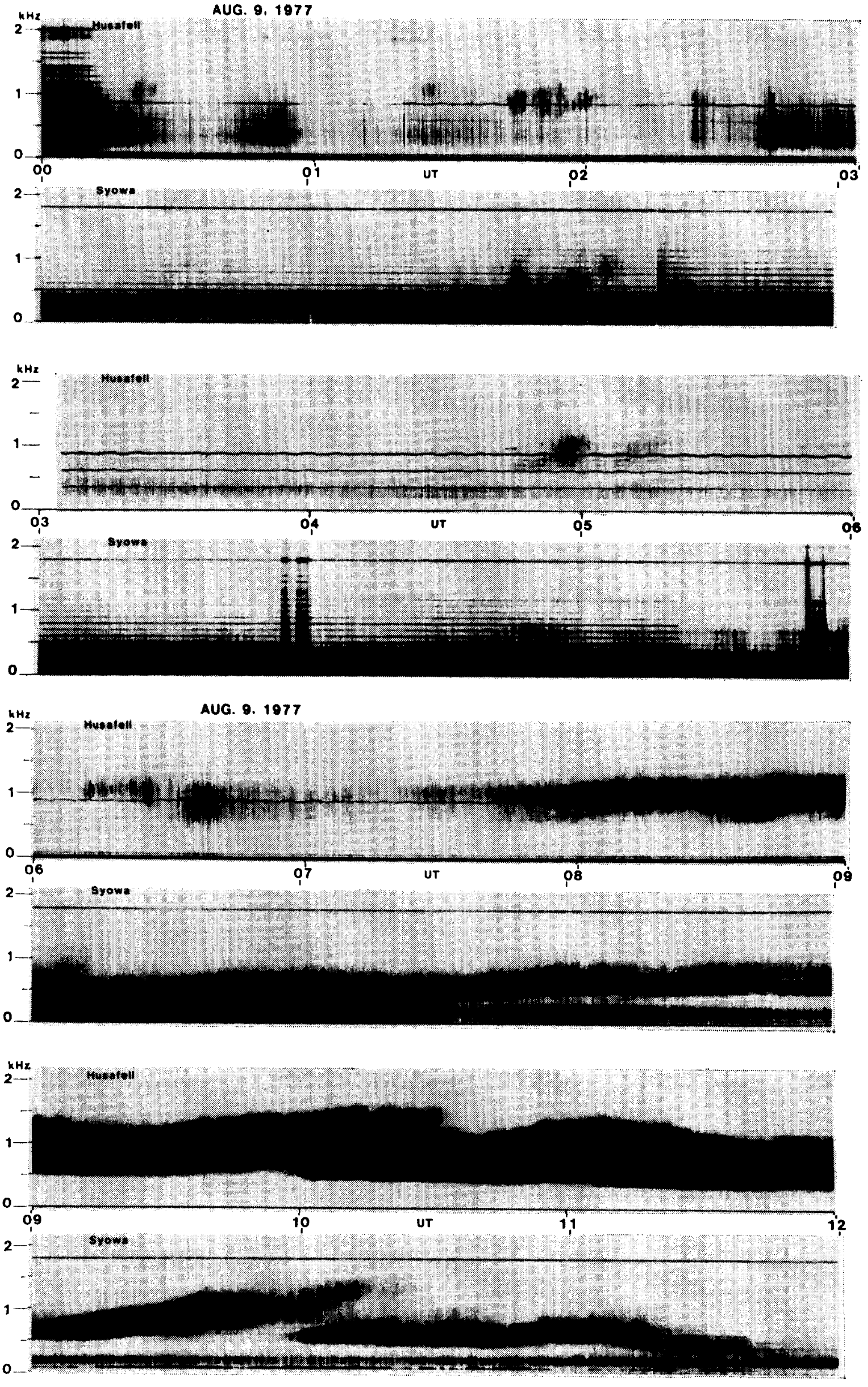

Fig. 7. Frequency-time spectra of ELF emissions observed at conjugate-pair stations in the same time interval as shown in Fig. 6.

1) Calibration of absolute emission intensity

Absolute emission intensities were calibrated by two methods. The first is a theoretical method using antenna circuit calculation and amplifier gain. The second calibration is an observational technique using Omega signal intensity observed at Syowa and Husafell. At Husafell we received Omega signals emitted from Station A in Norway, and at Syowa we received signals from Station E in La Reunion. The ambiguity of the two methods was factor 2 or 3. Details of the first method were given by MAKITA (1979) and the second technique was shown by SATO (1982).

2) Power spectral analysis

Emission power spectra are obtained by using the FFT (Fast Fourier Tranform) spectrum analyzer. Figure 6 shows 30-min averaged power spectra observed at the conjugate-pair stations in the time interval of 06–16 UT on August 9, 1977. Frequency-time spectra in this time interval are shown in Fig. 7. In these power spectra, one of the peak power with the frequency of 0.2 kHz is atmospherics. It is clearly shown in Figs. 6 and 7 that the lower frequency band with the frequency from 0.3 kHz to 0.7 kHz at Syowa is stronger than that at Husafell in the time interval of 06–08 UT. However, in this time interval, higher frequency emission band with the center frequency

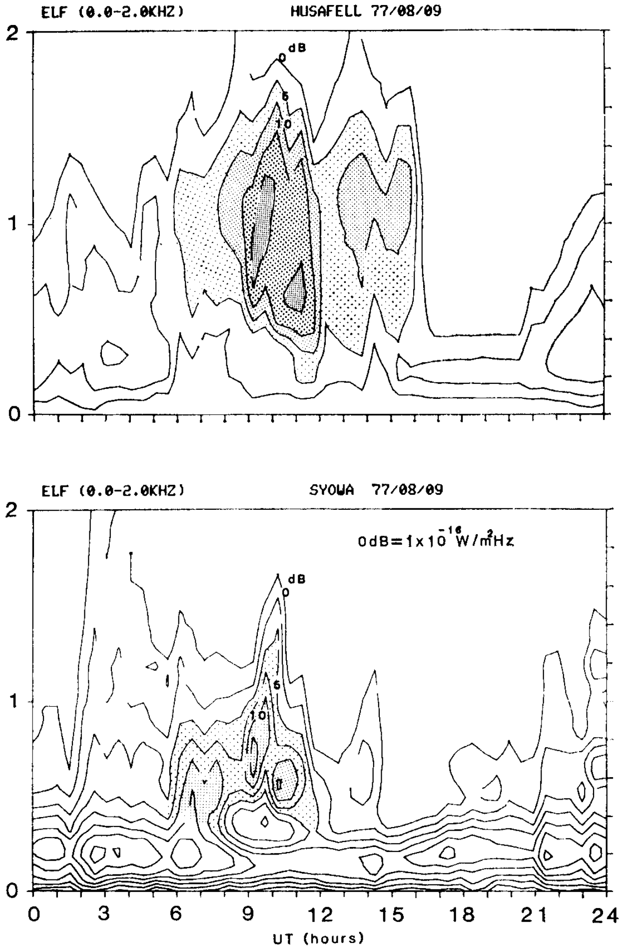

Fig. 8. Diagram of emission intensity observed at conjugate-pair stations in the time interval of 00–24 UT on the same day as Figs. 6 and 7.

of 1 kHz at Husafell is much stronger than that at Syowa. We can say that these emissions observed at the conjugate-pair stations in the interval of 06–08 UT show poor conjugacy. In the time interval of 0900–0930 UT, lower cutoff frequency ($\sim$0.4 kHz) in power spectra is nearly the same, and also the slope of intensity versus frequency in the frequency range of 0.4–0.7 kHz is almost the same at the conjugate-pair stations as shown in Fig. 6. However, the intensity of higher frequency component ($f>0.7$ kHz) at Husafell is about 10 dB stronger than that at Syowa. After 10 UT, the emission intensity at Husafell became stronger in the whole frequency range. Especially in the higher frequency range ($f>1$ kHz), the emission intensity at Husafell is more than 15 dB stronger than that at Syowa.

Figure 8 shows the diagram of emission intensity observed at the conjugate-pair stations in the time interval of 00–24 UT on the same day as Figs. 6 and 7. From this diagram it is clearly found that polar chorus emissions with low frequency bands (0.4 kHz) at Syowa started in the morning (06 UT), and emission frequency increased with time up to 1.3 kHz. Then new emissions with low frequency band (0.6 kHz) reappeared in the interval of 10–11 UT. The diagram of emission intensity at Husafell shows that emissions with higher frequency band (1 kHz) started from 06 UT. The characteristics of emission patterns in the interval of 09–12 UT are nearly the same as that at Syowa. However, the emission intensity at Husafell after 12 UT became much stronger than that at Syowa. Furthermore, it is found from Figs. 6–8 that higher cutoff frequency of polar chorus is about 1 kHz at Syowa, and that at Husafell extends over 1.5 kHz. By using this diagram, we can easily find dynamic characteristics of emission frequency and intensity at the conjugate stations.

4. Statistical Characteristics of Emission Occurrences

Statistical characteristics of ELF emissions ($0.3<f<2$ kHz) are examined by using f-t spectra. Diurnal variations of polar chorus occurrences observed at Syowa and

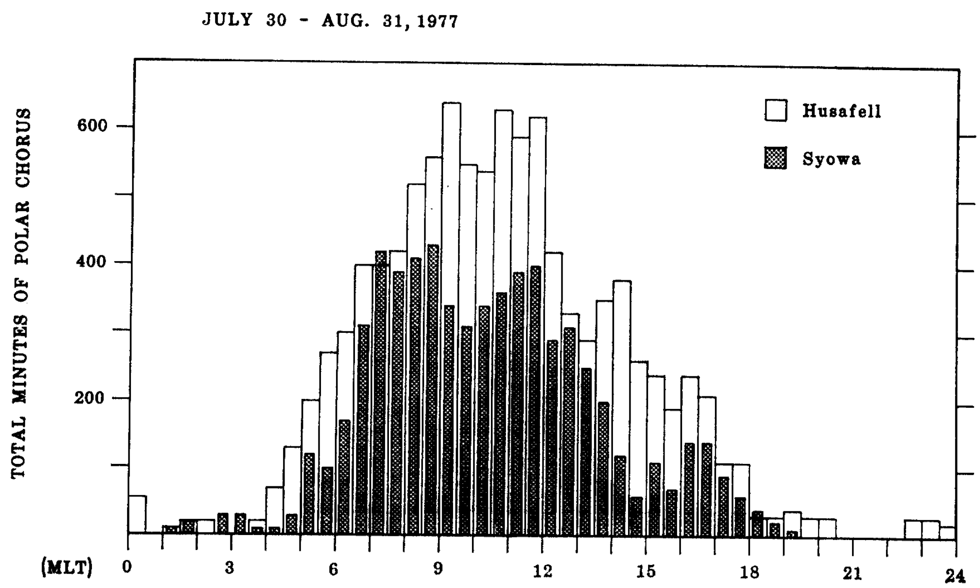

Fig. 9. Diurnal variations of polar chorus occurrences observed at Syowa and Husafell.

Husafell for 33 days are shown in Fig. 9. It is evident from this figure that polar chorus emission occurrences have a peak during daytime at the conjugate-pair stations. The diurnal variations of polar chorus emission at Syowa show the same characteristics as those reported by HAYASHI *et al.* (1968). In the time interval of 06–08 and 12–14 UT the occurrences are nearly the same at the conjugate stations. However, in the other time interval polar chorus emissions are more often observed at Husafell than at Syowa. It is interesting that the sub-peak in the interval of 16–17 UT at Syowa, HAYASHI *et al.* (1968) called this sub-peak a late afternoon chorus, is not so clear at Husafell.

Furthermore, we examined the relation between geomagnetic activity and polar chorus occurrences at the conjugate stations. Figure 10 shows *Kp* dependence of

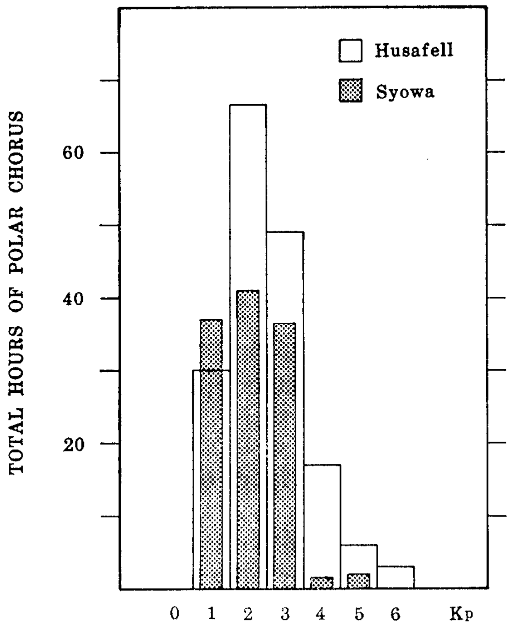

Fig. 10. Kp dependence of polar chorus occurrences observed at Syowa and Husafell.

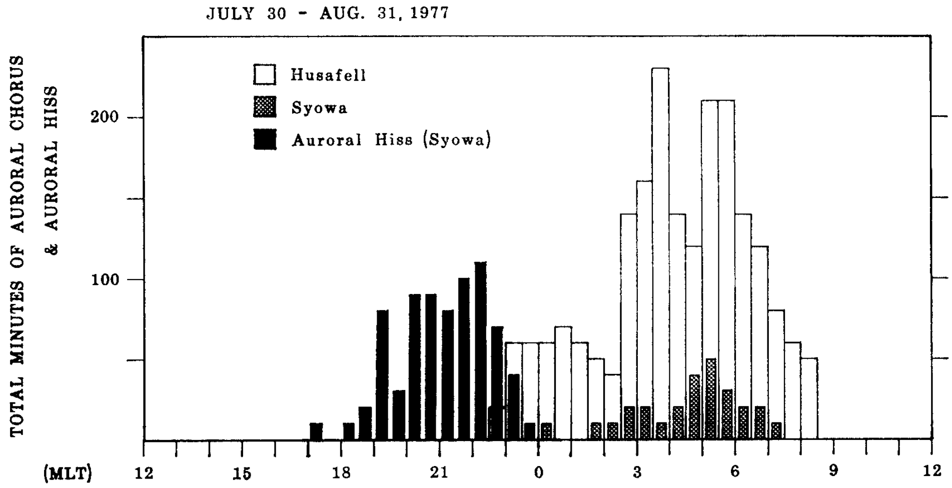

Fig. 11. Diurnal variations of auroral chorus and auroral hiss occurrences observed at the conjugate stations during the same period as Fig. 9.

polar chorus occurrences. It is evident that in the quiet condition ($Kp=1$) emissions are more often observed at Syowa than at Husafell. In the moderate ($Kp=2$–3) and disturbed periods ($Kp \geq 4$) emissions are more often observed at Husafell than at Syowa.

Figure 11 shows the diurnal variations of auroral chorus and auroral hiss occurrences observed at the conjugate stations during the same period as Fig. 9. Auroral hiss emissions are observed only at Syowa. On the other hand, auroral chorus emissions are mostly observed at Husafell as reported by SATO *et al.* (1980).

5. Summary and Conclusion

From the studies of conjugacy of ELF emissions observed at Syowa in Antarctica and Husafell in Iceland it is concluded that auroral chorus and polar chorus emissions do not always show good conjugacy as reported by SATO *et al.* (1980). The local time dependence of f-t spectra and absolute intensity of ELF emissions observed at the conjugate-pair stations are summarized as follows:

(1) Auroral chorus emissions observed in the early morning (00–06 MLT) shows low conjugacy. The emissions observed at Husafell are strong enough and have higher frequency bands compared with those at Syowa.

(2) Polar chorus emissions appear mostly after 06 MLT in the morning. Intensity of lower frequency bands ($f<0.7$ kHz) at Syowa is stronger than at Husafell in the time interval of 06–08 MLT. However, in this time interval, higher frequency bands ($f>1$ kHz) are much stronger that at Syowa. We can say that emissions in the interval of 06–08 MLT show week conjugacy.

(3) Conjugacy of emission patterns is more complex in the daytime sector (09–14 MLT), but the following tendencies are found: i) Differences in the center of emission frequency at the conjugate-pair stations are less than 0.2 kHz in the interval of 09–11 MLT, and become larger up to 0.5 kHz in the interval of 11–14 MLT. ii) Power of emissions in the frequency range higher than 0.8 kHz at Husafell is about 10 dB stronger than that at Syowa. iii) Higher cutoff frequency of polar chorus emissions is about 1 kHz at Syowa, and that at Husafell extends over 1.5 kHz.

(4) Statistically, polar chorus emissions are more often observed at Husafell than at Syowa in the whole local time. Furthermore, polar chorus occurrences at the conjugate stations depend on geomagnetic activity. When geomagnetic activity is quiet ($Kp \leq 1$) emissions are often observed at Syowa, but emissions are more often observed at Husafell in the moderate and disturbed periods ($Kp \geq 2$).

The above facts may indicate that the generation and propagation characteristics of ELF emission are different in the northern and the southern hemisphere. In order to examine physical processes relating to these conjugate phenomena, we must take into account the different geophysical conditions at the conjugate-pair stations. The differences in geophysical parameters at Husafell and Syowa are as follows: i) The total intensity of magnetic field is about 45000 γ at Syowa and 52000 γ at Husafell. ii) The dip angle is 65° at Syowa and 75° at Husafell. iii) Geographic local time is delayed one hour at Husafell and advanced three hours at Syowa in comparison with geomagnetic local time; furthermore, sunlit time in the ionosphere is very different at the both stations in the summer and the winter seasons. iv) Geomagnetic field lines are asymmetrically distorted with respect to the solar wind direction. SATO *et al.* (1980) proposed a phenomenological model to explain low conjugacy phenomena for auroral hiss and auroral chorus by taking into account anisotropy of mirror height and ambient plasma density in the both hemispheres. To confirm their model and furthermore to explain the conjugate phenomena for the local time dependence of f-t spectra and for the difference of emission intensity shown in this paper, additional data recorded simultaneously on the ground networks at conjugate hemispheres and aboard satellites for are needed.

Acknowledgments

We wish to thank Director T. NAGATA, Prof. T. HIRASAWA, Drs. R. FUJII, T. ONO and Mr. H. YAMAGISHI of the National Institute of Polar Research, and Mr. S. SHIBUYA of Yamagata University for their valuable discussions and suggestions. Our thanks are also due to Dr. K. MAKITA, Messrs. K. Uchida, K. Nakagawa and M. Suzuki for their kind help with the computer analysis.

It is our pleasure to acknowledge all members of the 18th Japanese Antarctic Research Expedition, and the staff members of the CRPE, France.

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(*Received September 21, 1982; Revised manuscript received December 13, 1982*)